



III-V/SOI vertical cavity laser structure for 120 Gbit/s speed

Park, Gyeong Cheol; Xue, Weiqi; Mørk, Jesper; Semenova, Elizaveta; Chung, Il-Sug

Published in:
Integrated Photonics Research, Silicon and Nanophotonics 2015

Link to article, DOI:
[10.1364/iprsn.2015.jt5a.2](https://doi.org/10.1364/iprsn.2015.jt5a.2)

Publication date:
2015

Document Version
Peer reviewed version

[Link back to DTU Orbit](#)

Citation (APA):
Park, G. C., Xue, W., Mørk, J., Semenova, E., & Chung, I-S. (2015). III-V/SOI vertical cavity laser structure for 120 Gbit/s speed. In *Integrated Photonics Research, Silicon and Nanophotonics 2015* [JT5A.2] Optical Society of America. <https://doi.org/10.1364/iprsn.2015.jt5a.2>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

III-V/SOI vertical cavity laser structure for 120 Gbit/s speed

Gyeong Cheol Park, Weiqi Xue, Jesper Mørk, Elizaveta Semenova, and Il-Sug Chung*

Department of Photonics Engineering (DTU Fotonik), Technical University of Denmark

Ørsted Plads, DK-2800 Kgs. Lyngby, Denmark

*ilch@fotonik.dtu.dk

Abstract: Ultrashort-cavity structure for III-V/SOI vertical cavity laser with light output into a Si waveguide is proposed, enabling 17 fJ/bit efficiency or 120 Gbit/s speed. Experimentally, 27-GHz bandwidth is demonstrated at 3.5 times of threshold.

OCIS codes: 140.7260, 200.4650, 050.6624.

1. Introduction

In optical interconnect applications, lowering the energy/bit defined as the energy used to generate a bit signal is one of key issues for light sources [1]. Recently, we have demonstrated a promising vertical cavity laser structure that is integrated onto a silicon-on-insulator (SOI) wafer and emits light laterally into a Si waveguide, hereafter denoted as silicon vertical-cavity in-plane-emitting laser (Si-VCIEL) [2]. In this Si-VCIEL structure, a high-index-contrast grating (HCG) works as a vertical reflector, as well as funnelling light into an in-plane Si waveguide [3].

Here, we report that a carefully-designed HCG with high reflectivity for TM polarized light (TM HCG) allows to realize a ultrashort cavity for the Si-VCIEL. Based on this design, we experimentally demonstrate a 3-dB bandwidth of 27 GHz at 3.5 times of threshold. Numerical simulations calibrated with experimental measurements show that the energy/bit can be as low as 17 fJ/bit at 0.8 mA while the speed can be as high as 120 Gbit/s at 5.0 mA.

2. Ultrashort-cavity design

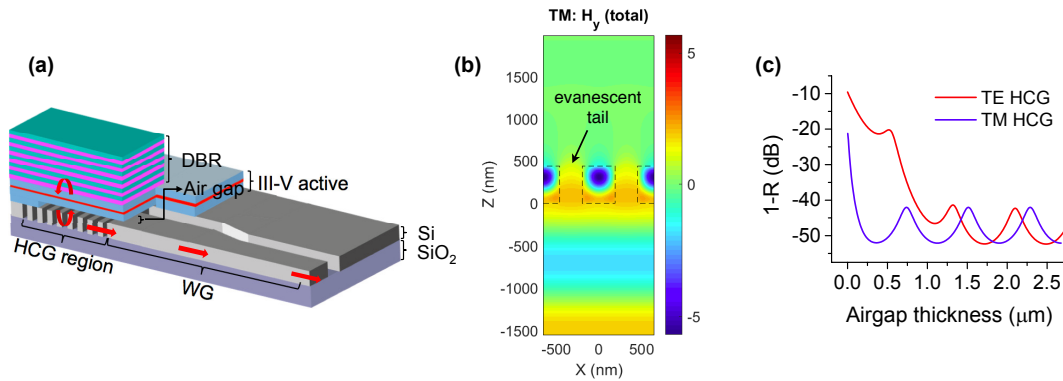


Fig. 1. (a) Schematic cross-section of Si-VCIEL. (b) Field profile, $H_y(x, z)$ around a TM HCG with an TM-polarized incident field from the bottom. (c) Reflectivity, R as a function of airgap thickness for TM HCG and TE HCG.

As shown in Fig. 1(a), the considered Si-VCIEL consists of a dielectric DBR, III-V active layers, and a Si HCG region that is connected to a Si ridge waveguide. Note that the HCG region and an output waveguide are formed in the same Si layer of an SOI wafer. There is an air gap between the III-V active layers and the Si HCG region. By reducing the thickness of the air gap, a very small cavity length can be achieved.

The air gap thickness is determined by two factors: the length of evanescent tail of the modes within the HCG and the reflection phase shift of the HCG. An example of the evanescent tail is shown in Fig. 1(b). By using a TM HCG

with a small period, the evanescent tail extension can be minimized [4]. In addition, the negative reflection phase may further reduce the airgap thickness. Fig. 1(c) shows that a TM HCG can reach 99.9 % reflectivity value at an air gap thickness less than 150 nm, which is about 0.1 times of wavelength.

3. Results and discussion

Based on the TM HCG with a very small air gap thickness, a Si-VCIEL has been fabricated, as shown in Fig. 2(a). The DBR is 6 pairs of Si/SiO₂ and the active material includes 7 InGaAlAs/InGaAlAs quantum wells (QWs). Fabrication processes are CMOS-compatible, which are the same as in [2] except that DBR is defined by dry-etching instead of lift-off. The laser sample was optically pumped through the DBR. For small signal characterization, the 980-nm pumping light was modulated by using a high-speed modulator. The emission light was directed measured by a high-speed photodetector which is connected to a network analyzer. The frequency responses of the modulator and photodetector are subtracted.

Fig. 2(b) shows the small-signal response spectrum measured at 3.5 times of threshold. This shows that the 3-dB bandwidth is as high as 27 GHz, which is the highest directly modulated bandwidth from any type of Si-integrated laser to our knowledge. Due to the saturation in the modulator, we cannot increase the pumping power. Thus, after calibrating the rate equations model with experimental measurements, we numerically investigate several different cases. The quantum confinement factor is calculated from FDTD simulation.

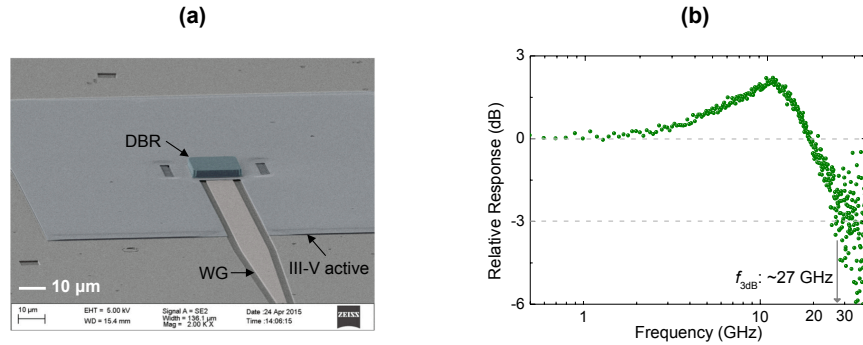


Fig. 2. (a) Scanning electron microscope (SEM) image of a fabricated Si-VCIEL sample. (b) Small signal modulation spectrum at 3.5 times of threshold and at room temperature.

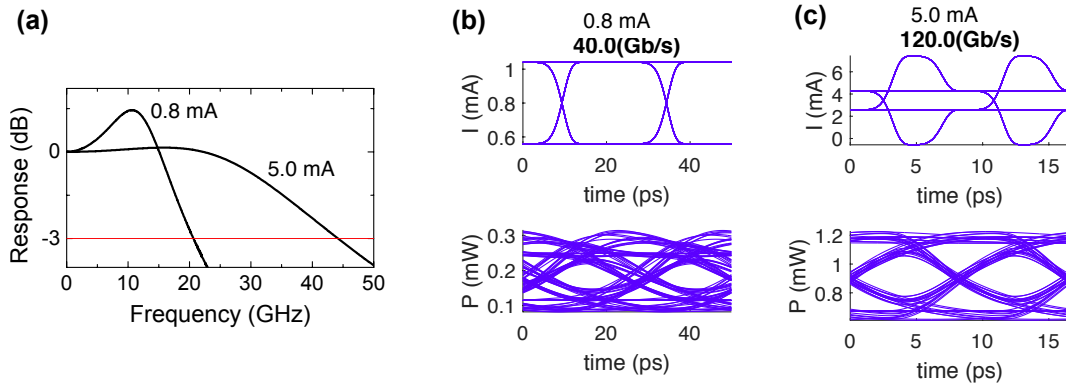


Fig. 3. Sample figure with preferred style for labeling parts.

As shown in Fig. 3(a), the response is quite flat at an injection current of 5.0 mA while the 3-dB frequency is as high as 20 GHz at 0.8 mA. Figures 3(b) and 3(c) show eye-diagram simulations performed at 0.8 mA and 40 Gbit/s and at 5.0 mA and 120 Gbit/s, respectively. For the 5.0 mA case, a two-step pre-equalization is used.

For both cases, eye is clearly open. In the 0.8-mA injection case, the energy/bit is as low as 17 fJ/bit. Since the average output power is about 200 μW, the bit error rate (BER) can be lower than 10^{-12} without forward error

correction (FEC). Often, nano lasers with very small energy/bit requires the FEC, which consumes 300 fJ/bit to 3 pJ/bit [5]. Thus, our Si-VICIEL appears promising for chip-level optical interconnects.

In the 5.0 mA case, the speed is as high as 120 Gbit/s. This high speed might be desirable for high-performance computer applications. Since 56 Gbit/s speed can be achieved at slightly above 1 mA current, the lifetime reliability of this laser could be improved, compared to conventional VCSELs.

4. Conclusion

We have proposed an ultrashort cavity vertical cavity laser structure based on TM HCG implemented on a SOI wafer. The experimentally measured bandwidth of 27 GHz at 3.5 times of threshold proves the proposed cavity concept works.

Acknowledgement

The authors gratefully acknowledge support by the Danish Council for Independent Research through FTP program (Grant No. 0602-01885B), the Innovation Fund Denmark through HOT project (Grant No. 5106-00013B), and Villum Foundation through NATEC centre of excellence.

References

1. D. A. B. Miller, Proc. IEEE **97**, 1166 (2009).
2. G. C. Park, W. Xue, A. Taghizadeh, E. Semenova, K. Yvind, J. Mørk, and I.-S. Chung, "Hybrid vertical-cavity laser with lateral emission into a silicon waveguide," *Laser & Photon. Rev.* **9**, L11 (2015).
3. I.-S. Chung and J. Mørk, "Silicon-photonics light source realized by III-V/Si-grating-mirror laser," *Appl. Phys. Lett.* **97**, 151113 (2010).
4. I.-S. Chung, "Study on differences between high contrast grating reflectors for TM and TE polarizations and their impact on VCSEL designs," arXiv 1506.00161 (2015).
5. R. S. Tucker and K. Hinton, "Energy consumption and energy density in optical and electronic signal processing," *IEEE Photon. J.* **3**, 821 (2011).